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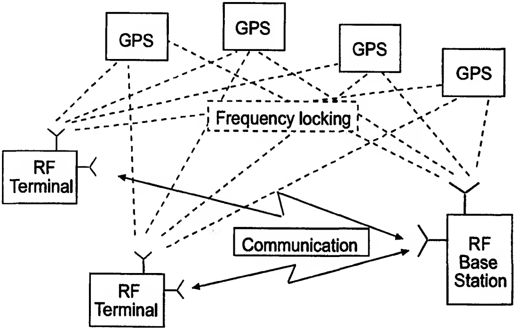

(57) Abstract

The invention relates to a method and an arrangement at a mobile radio communications system which includes at least one base station and at least one radio terminal, and which makes possible frequency locking of the oscillator frequency in the base station, respective the radio terminal, to a global satellite frequency.

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ARRANGEMENT AND METHOD AT A MOBILE RADIO COMMUNICATIONS SYSTEM

The present invention relates to a method and an arrangement at a mobile radio communications system including at least one base station and at least one radio terminal.

BACKGROUND OF THE INVENTION

The communications systems of today and of the future, with radio based access networks, so called RLL ("Radio in the Local Loop")-systems, need high reliability and capacity to be a cost efficient alternative to technologies based on copper wire, coaxial cable or optical fibre. Transmission of speech, video and data with digital radio can simplify, shorten and also make the necessary installation of a complete infrastructure cheaper. The demands for high transmission capacity means that advanced modulation methods are desirable to make it possible to provide the wanted capacity. Spectrum efficient modulation methods need a high signal-to-noise ratio in the detector of the receiver, and that the transmitted bit clock has been recovered, so called "clock recovery", when necessary low bit error content shall be achieved.

The communications systems of today are constructed to cope with not ideal time and frequency sources in communications equipment, which results in that much of the potential bandwidth is lost even at the design stage. For systems with stationary units outdoors, i.e. at places where a satellite system with a stable reference frequency/time is continuously accessible, there is a lot of capacity and performance to be gained by the invention.

Frequency fluctuations in the local oscillator of the receiver makes the utilisation of coherent detection more difficult, i.e. knowledge of exact phase, both when modulation of one carrier, so called "single carrier

modulation", and a plurality of carriers, so called "multi carrier modulation" is used. Impairment of the bit error content occurs when the frequency fluctuations exceeds certain maximum values, typically 1-10 ppm, depending on carrier frequency and modulation.

The use of carrier frequencies above the UHF-band, probably 5-80 GHz, will increase concurrently with the need for bandwidth and a deregulated market. Cheap radio terminals for a mass market are made possible by new components, but the frequency stability in the local oscillators of the terminals will be of great importance to system performance and cost.

The problem consequently is that the local oscillators in the radio terminals of today have too poor frequency stability, which will impair the capacity and performance of the radio system.

The aim of the present invention is to solve this problem.

SUMMARY OF THE INVENTION

The above mentioned aim is achieved by a method and an arrangement at a mobile radio communications system which includes at least one radio terminal and at least one base station, at which reference equipment in said base station and in said radio terminal, which influence transmission respective reception of information between said base station and said radio terminal, is synchronised to a detected time/frequency reference transmitted from an external reference system.

Thanks to the fact that the external reference system has high frequency stability, the local oscillators in the base station and in the radio terminal will have the same stability.

An advantage moreover is that "expensive" bandwidth which is used at terrestrial radio communication between radio terminal and base station need not be utilised for

synchronisation of the reference equipment, i.e. the oscillators, because this is made via channels adapted to the external reference system, i.e. the satellite system.

In one embodiment according to the patent claim 4, a global satellite system, for instance GPS, is utilised, which results in high accuracy in the reference frequency and world-wide coverage.

In a preferred embodiment according to patent claim 14, a PLL is utilised to lock the oscillator frequency to the satellite frequency. The PLL is a cheap and easily obtainable component.

In another preferred embodiment according to patent claim 17, the by the PLL locked oscillator frequency is utilised to lock all local oscillators in the base station and in the radio terminal to achieve a completely coherent system.

Further characteristics of the invention are given in the other subclaims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, a detailed description of an embodiment of the invention is given with reference to the enclosed drawings, of which:

Figure 1 is a system survey of the invention;

Figure 2 is an alternative embodiment of the invention for indoor use;

Figure 3 shows the construction of the radio frequency part in the mobile terminal, respective the base station, according to the present invention;

Figure 4 shows the construction of a phase-locked loop.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

In the following the radio communications system according to the invention will be described with reference to the Figures 1-4. In connection with the description of

the radio communications system, a functional description of a very important component in the invention, namely the Phase-locked loop, is given. However, a definition is first given below of a number of abbreviations which are used throughout in the description.

BRAN	Broadband Radio Access Networks
DECT	Digital Enhanced Cordless Telecommunications
DVB	Digital Video Broadcasting
FDD	Frequency Division Duplexing
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
HIPERLAN	High Performance Radio LAN
IF	Intermediate Frequency
LMDS	Local Multipoint Distribution Service
LO	Local Oscillator
OFDM	Orthogonal Frequency Division Multiplex
PLL	Phase-Locked Loop
ppm	parts per million
RF	Radio Frequency
RLL	Radio in the Local Loop
TDD	Time Division Duplexing
VCXO	Voltage Controlled Crystal Oscillator

The general problem which the invention intends to solve is the possibility to build spectrum efficient communications systems with high performance at low cost. Spectrum is a limited resource which should be utilised as efficiently as possible. By utilising a universally accessible frequency/time reference, systems can be built which give high system performance, i.e. high bit/s/Hz/unit area. Several parameters must be taken into consideration in order to find good solutions of this complex optimisation problem, for instance system specifications, cost/performance for components, spectrum efficiency contra cost, immunity to noise, frequency in question etc.

The invention solves the problem of frequency stability by utilising a global satellite system. By that the data capacity can be increased by possibility to use more efficient modulation methods, and that better performance is achieved thanks to negligible frequency and phase errors at detection. Besides no overhead (control bits; training bits) is wasted, due to synchronisation of receivers within the transmitted time slots, which is needed if no reference is accessible for the whole system.

Today there are two globally accessible satellite systems with possibility to get an exact position, time and frequency, namely the American GPS and the Russian GLONASS. GLONASS is rather similar to GPS, but is inferior to GPS regarding supply of receivers, so only GPS is described below.

GPS consists of 24 rotating satellites and has been a tremendous success, which means that the system is used in more and more applications. To civil users the C/A-code is accessible, where a PN-code is repeated every ms with a chip frequency of 1,023 MHz at 1575,42 MHz. Superimposed with a rate of 50 bit/s, system data is transmitted which i.a. contains satellite data, system time and status messages. Each satellite is equipped with 4 atomic clocks. By, in the receiver, measuring on the transmitted signals, position, time and frequency can be appointed with a very high accuracy. GPS consequently makes possible access to "atomic clock performance" at any place on the globe at a very low cost.

To make a GPS-receiver to deliver an exact time is required that it can lock to 4 satellites, or that the position is known and that one satellite is accessible. These conditions are always fulfilled if the receiver is placed at a high place outdoors, because it is sufficient that it once has contact with 4 satellites to appoint its position (after that it is sufficient with contact with one satellite). Of course it will be an advantage to measure on

a plurality of satellites. The accessibility of the reference signal by that can be guaranteed to almost 100%, which is fundamental to the function of the communications system.

To sum up, there today exists a global system, GPS, which at low cost gives possibility to a very stable frequency and time reference, typically ± 100 ns, and a frequency stability of 10^{-12}. Performance varies, depending on the quality of the receiver. The cost of a GPS-receiver is low even today, and it will be even lower. It is, for instance, possible to buy GPS-receivers with display for about 1000 kr in the shops. A receiver which can be used for the invention is estimated to be manufactured at a price of a few hundred kr even today, which should be related to the advantages the invention will bring about.

The invention describes how frequency stability and synchronisation can be improved for a radio communications system with a satellite system, such as GPS or GLONASS, by phase locking the oscillators in radio terminals and base stations to a common reference. In this way one replaces completely, or simplifies, frequency correction and clock recovery in the obtained base band signal, which normally is made by transmitted training sequences.

It should be realised that in the radio communication systems of today, training sequences takes a large part of the total amount of data. For instance is in DECT used 32 bits in each time slot ("burst") of totally 388 data bits, which corresponds to 7,6 %. In HIPERLAN/1 is 450 bits used for 1 block, to maximally 47 blocks of 496 bits, which corresponds to 2-47%. In the present invention these data bits instead can be used for data information, which results in an increase of capacity.

The comparatively large frequency variations which occur in the oscillators at high carrier frequency (>5 GHz) are reduced, and the invention consequently also improves reliability and bit error content at transmission both from

base station to terminal (downlink), and from terminal to base station (uplink). It consequently also is possible to use coherent detection in the uplink, thanks to phase locking of the reference frequencies, which further contributes to better system performance.

It should be realised that if ATM shall be transported over radio, the bit error contents must be very low, because ATM is designed for reliable media. If the bit error content for instance exceeds 10^{-5}, then retransmissions will reduce the data rate for transmissions considerably, because retransmissions will be more and more dominating. The same is true if IP-data is transported, at which, at too high bit error content, the retransmissions will have a significant influence. Radio systems for data traffic therefore shall be designed for bit error contents of 10^{-8} -10^{-11} after encoding.

The system arrangement with frequency and phase locking of the reference frequencies in the terminals and base stations of the communications system is shown in Figure 1. The communications system is characterised in that synchronisation is made via a global satellite system with time and frequency references, whereas interactive transmission of wanted information is made via the terrestrial radio access network. The system is also possible to use for one-way terrestrial distribution of, for instance, digital TV according to DVB.

The invention is principally intended for stationary outdoor systems, but can also be used indoors if the receiver suitably located, or if a GPS-repeater is used, see Figure 2. The GPS-repeater amplifies and distributes the signal indoors. Because the GPS-part in a receiver indoors will have the same GPS-signals as the outdoor unit of the building, it can appoint time/frequency and a position. Time and frequency is exact, whereas the position will be slightly wrong. The appointed position, however, is

sufficiently exact for most applications within a specific building, typically ± 100 m.

From a general point of view it can be said that the radio terminal in the first place should be stationary during the communications session, because locking to the GPS-satellites depends on the position. Mobility during a communications session demands that the reference frequency maintains its stability in spite of that the GPS-receiver is subject to Doppler shift, and the position in relation to the satellites is changed. By extended logic in the phase locked loop for the reference frequency, the stability can be maintained during mobile sessions. A certain impair of the stability occurs when the locking to GPS has been lacking for a longer period. Today is obtained typically better than 10^{-10} after 24 hours without locking to GPS, which yet is considerably better than internal locking with the stability 1-25 ppm.

In the alternative embodiment of the invention a position can be appointed indoors and a coherent system be achieved, which otherwise normally is not possible with a satellite system, due to low signal strength from the satellites. An improved frequency stability for a communications system with mobile terminals then can be achieved when the logic in the reference loop is extended so that the locking is corrected if the GPS-signal is lost.

In Figure 3 is shown how the RF-device, i.e. the high frequency part of the terminal and the base station which is the critical part of the system, is frequency locked by the satellite reference system, in this case GPS. In Figure 3 is also shown how GPS makes possible frequency locking of IF (Intermediate Frequency)- and base band oscillators to the same frequency reference for a compete coherent system. In addition the GPS-signal also can be used to give time reference to base band circuits.

A GPS-antenna located on the top of the RF (Radio Frequency)-part of the terminal or base station receives

signals from a necessary number of GPS-satellites to obtain position and time. It is also possible to locate the GPS-antenna externally and connect it to the input amplifier of the GPS-part if the location of the whole RF-part makes reception of satellite signals more difficult. The RF-part consequently utilises the reference frequency f_i, which is extracted by means of normal GPS-detection and locking to any type of controllable crystal oscillator "Voltage Controlled Crystal Oscillator" VCXO. A phase locked loop, PLL, consisting of a phase detector (P.D.), frequency divider and loop filter, and supplemented with logic for correction of long-time variations, is normally used to produce the oscillator reference frequency f_0 , which is controlled by detected GPS-signals.

The principle of how a PLL (Phase Locked Loop) functions is described briefly below with reference to Figure 4.

When the loop in Figure 4 is locked, one knows that f_i (the reference frequency) is equal to f_0 he (the oscillator reference frequency). This is the unique distinctive feature of the phase-locked loop, PLL; no frequency error exists. Only a phase difference between the input signal f_i and the signal f_0 from the VCO exists. This phase difference $\theta_0-\theta_i= \theta_e$ is called the static phase difference. θ_e is the input parameter to the phase detector when the loop is locked and is required to make the phase detector generate a DC voltage V_d at the output which, when it is amplified in a DC amplifier, will generate exact sufficient voltage V_0 to make the VCO-frequency deviate with the amount Δ_f. If f_i increases, then in that case Δ_f will increase, and θ_e must increase to provide more voltage V_o to provide that the VCO-frequency follows the reference frequency f_i. The definition of locked is that $f_i=f_o$ and the loop will follow every change in the reference frequency f_i.

The voltage controlled crystal oscillator (VCXO) in Figure 3 corresponds to the VCO in Figure 4.

In Figure 3 can be seen that the oscillator reference frequency f_o is derived from VCXO and is transferred to RF-synthesizers, by which f_o is utilised in the local oscillators as mixing frequency. The oscillator reference signal f_0 is also transferred to the intermediate frequency part and the base band part of the radio terminal (the mobile terminal).

Consequently, the reference frequency f_i can be used to lock all the oscillators which are included in the terminal and base station equipment. Figure 3 shows how the frequency synthesizers for the RF-blocks lock to reference frequencies f_o. Normally RF-synthesizers are used as local oscillators for transmission and reception when it is a question of a plurality of carrier frequencies. Depending on which frequency band that is utilised for communication, different numbers of stages can be included in up and down conversion between RF (radio frequency), IF (intermediate frequency) and base band. If the whole radio system shall be coherent, also oscillators in IF and base band circuits must be locked to the obtained reference frequency, i.e. $f_o = f_i$ (see Figure 4).

With a completely coherent system, more advanced modulation methods and optimal detection can be used, both for transmission of information from base station to terminal (downlink) and vice versa (uplink). Also quite distributive transmission from one transmitter to several receivers can be improved and simplified by the described phase locking of the system. It should also be noticed that the invention functions at full interactive communication both with FDD and TDD, though the gains are comparatively larger with TDD thanks to synchronisation of downlink/uplink. The whole communications system may of course be coherent irrespective of if zero or a plurality of IP-stages are included in the equipment.

It should be realised that radio based communications equipment can consist of different blocks, depending on

which carrier frequency/frequencies that are used. By direct mixing to base band (homodyne receiver) the IF-blocks are eliminated. With carrier frequencies over 10 GHz one or more IF-stages are normally included to fulfil filter requirements and other system specifications.

To sum up can be said that the most important characteristics of the invention are that:

all oscillators which are included in terminals and base stations and influence transmission/reception are frequency locked to a satellite reference. The reference f_0 is created both in terminals and base stations by the internal reference being locked to the detected satellite signals f_i;

the communications system by that achieves higher performance by more and more spectrum efficient modulation and coherent detection being possible to use both in downlink and uplink;

frequency bands which have been globally set aside for satellite references are utilised, which means that valuable bandwidth is saved for communication in the frequency bands which the applications relate to.

The invention consequently describes a new radical way to build radio communications systems with possibility to performance improvements which, thanks to the component development, have been possible to implement at low cost.

The invention can in principle in easily be used for all radio systems with fixed antennas mounted outdoors. The invention is very suitable for RLL-systems where there are demands for spectrum efficient modulation and low bit error content when high carrier frequencies are used, for instance LMDS (LMDS is interactive broadband radio systems which operate on frequencies over 10 GHz, typically 28 or

40 GHz, with a possibility for about 25 Mbit/s data rate to customer, and 3 Mbit/s from customer). Also distribution of terrestrial TV with OFDM can be improved with frequency and phase locking of the local oscillators of the receivers to a satellite based reference system. The invention can also be used in other configurations, for instance indoors with GPS-repeaters, and for mobile radio systems, but the applications above are the most apparent.

In Europe the BRAN-project has started, which i.a. shall standardise an LMDS-system. The invention can be introduced at suitable point of time in the standardisation, with possibilities for future licence receipts.

Synchronisation of radio base stations, advanced measuring systems, and data networks, by means of GPS is made to an ever greater extent, due to the low price of GPS and high performance in comparison with other solutions. The invention expands the use of time and frequency references f_i from satellites to synchronise and frequency lock a complete radio communications system, i.e. both base stations and terminals.

In comparison with the use of frequency stable internal reference oscillators, a lot can be gained by the invention. Internal reference oscillators with frequency stability better than 0,1—1 ppm are not practically suitable because of high cost, especially for mass market production where the price is very critical. Generally the oscillators constitute a large part of the cost of the receivers. With a stability of 5-20 ppm, which is normal in many standards (for instance DVB, HIPERLAN and DECT) the absolute frequency error Δf_c will be up to 100 kHz in the 5 GHz band, and 560 kHz in the 28 GHz band, which of course will contribute to impaired performance and requires expensive counter-measures. With a typical long-time stability better than 10^{-11}, i.e. 0,00001 ppm, which (easily) can be attained with external satellite locking of

terminal and base station references, a frequency error is obtained which is less than 1 Hz.

Parts of the available, transmitted bandwidth can be used to train the receiver. By transmitting known sequences, so called "training sequences", the receiver can be synchronised. Pilot tones is another method which can be used but will, like training sequences, take bandwidth which might be used for useful data.

It is also possible to utilise characteristic qualities of the transmitted signal to "blindly" train the receiver. The method requires signal handling, but the result will not be as good as a stable frequency/time reference.

Use of a local reference signal, distributed via an independent terrestrial transmission network with limited coverage, might be used as reference for radio communications systems (both base station and terminal). Local reference signals are not used, as far as we know, to synchronise terminals, and has disadvantages compared with the invention. For instance is the signal not globally accessible, and is probably not of as good a quality as the GPS-system, because the American national defence is responsible for the operation.

The above discussed is only to be regarded as advantageous embodiment of the invention, and the extent of protection of the invention is only limited by what is specified in the enclosed patent claims.

PATENT CLAIMS

1. Method at a mobile radio communications system including at least one base station and at least one radio terminal, c h a r a c t e r i s e d in that reference equipment in said base station and in said radio terminal, which influence transmission respective reception of information between said base station and said radio terminal, is synchronised to a detected time/frequency reference (f_i), transmitted from an external reference system.

2. Method according to patent claim 1, c h a r a c t e r i s e d in that said reference equipment consists of oscillators.

3. Method according to any of the patent claims 1 or 2, c h a r a c t e r i s e d in that said external reference system consists of a satellite system.

4. Method according to patent claim 3, c h a r a c t e r i s e d in that said satellite system consists of a global satellite system, preferably GPS or GLONASS.

5. Method according to patent claim 3 or 4, c h a r a c t e r i s e d in that said oscillators in said radio terminal and in said base station are synchronised to the time/frequency signals (f_i) of said satellite system, and that interactive transmission of data between said base station and said radio terminal is made via the terrestrial radio access network.

6. Method according to patent claim 5, c h a r a c t e r i s e d in that said oscillators are phase locked (f_o) to the from the satellite system transmitted time/frequency reference (f_i).

7. Method according to any of the patent claims 5 or 6, c h a r a c t e r i s e d in that said radio terminal and said base station on the one hand includes a satellite receiver, for instance GPS-receiver, for reception of the

time/frequency reference from said satellite system, and on the other a receiver/transmitter for the terrestrial radio access network.

8. Arrangement at a mobile radio communications system including at least one base station and at least one radio terminal, c h a r a c t e r i s e d in that reference equipment in said base station and in said radio terminal, which influence transmission respective reception of information between said base station and said radio terminal, is synchronised to a detected time/frequency reference (f_i) transmitted from an external reference system.

9. Arrangement according to patent claim 8, c h a r a c t e r i s e d in that said reference equipment are oscillators.

10. Arrangement according to patent claim 8 or 9, c h a r a c t e r i s e d in that said external reference system is a satellite system.

11. Arrangement according to patent claim 10, c h a r a c t e r i s e d in that said satellite system is a global satellite system, preferably GPS or GLONASS.

12. Arrangement according to any of the patent claims 10 or 11, c h a r a c t e r i s e d in that said radio terminal and said base station on the one hand includes an external antenna unit for reception of the time/frequency reference (f_i) from said satellite system, and on the other another antenna unit for transmission and reception of information via the terrestrial radio access network.

13. Arrangement according to patent claim 12, c h a r a c t e r i s e d in that said external antenna unit is connected to a satellite detector, preferably a GPS-detector, which senses the time/frequency reference (f_i) and locks this to a controllable oscillator.

14. Arrangement according to patent claim 13,

c h a r a c t e r i s e d in that a phase locked loop (PLL) attends to the locking of the frequency (f_o) of the oscillator to the frequency reference (f_i).

15. Arrangement according to patent claim 14, c h a r a c t e r i s e d in that said phase locked loop includes phase detector, frequency divider, loop filter, and unit for correction of long-time variations.

16. Arrangement according to patent claim 15, c h a r a c t e r i s e d in that said oscillator is a controllable crystal oscillator (VCXO).

17. Arrangement according to any of the patent claims 8-16, c h a r a c t e r i s e d in that said locked oscillator frequency (f_o) is used to lock all local oscillators in said radio terminal and in said base station to the same common reference frequency.

18. Arrangement according to patent claim 17, c h a r a c t e r i s e d in that said oscillator frequency (f_o) is used for mixing to intermediate frequencies and base band frequencies to obtain a coherent system.

19. Arrangement according to any of the patent claims 8-18, c h a r a c t e r i s e d in that said radio terminal is connected via, for instance, a repeater to a stationary satellite receiver, which stationary satellite receiver is arranged in a place where it continuously can communicate with said satellite system.

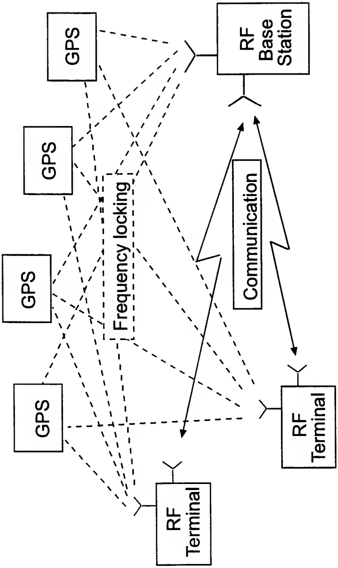

GPS
GPS
GPS
GPS
Frequency locking
RF
Base
Station
Communication
RF
Terminal
RF
Terminal

Figure 1

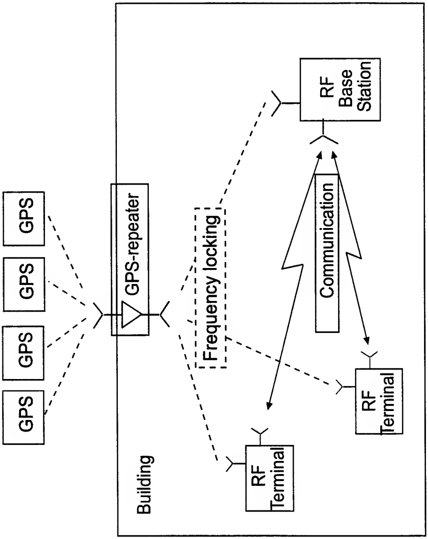
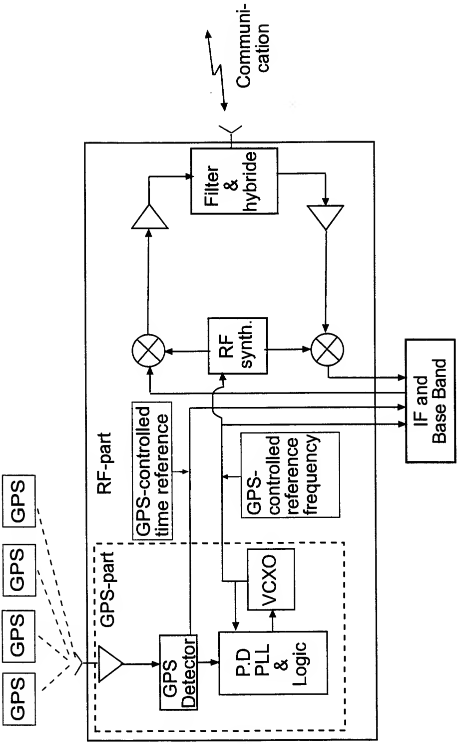

GPS
GPS
GPS
GPS
GPS-repeater
Frequency locking
Communication
RF Base Station
RF Terminal
RF Terminal
Building

Figure 2



Communi-
cation
Filter
&
hybride
RF
synth.
IF and
Base Band
RF-part
GPS-controlled
time reference
GPS-
controlled
reference
frequency
GPS-part
VCXO
GPS
Detector
P.D
PLL
&
Logic
GPS
GPS
GPS
GPS

Figure 3

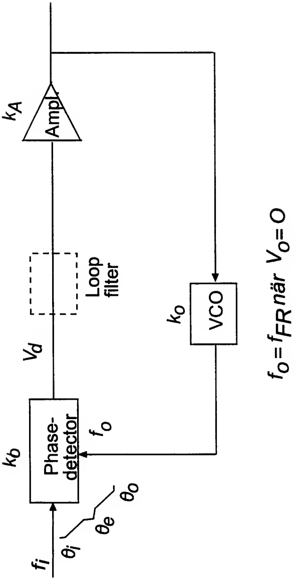

k_A
Ampl.
Loop filter
V_d
k_o
VCO
k_b
Phase-detector
f_o
f_i
θ_i
θ_e
θ_o
$f_o = f_{FR}$ när $V_o = O$

Figure 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 99/00504

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04J 3/06, H04B 7/26
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04B, H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5367524 A (KENNETH E. RIDEOUT, JR. ET AL), 22 November 1994 (22.11.94), column 2, line 12 - line 48; column 3, line 22 - line 37	1-5,7-11
Y		6,12-18
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Y	US 5003272 A (DIETER J. JANTA ET AL), 26 March 1991 (26.03.91)	6
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Y	US 5245634 A (NIMROD AVERBUCH), 14 Sept 1993 (14.09.93)	12-18
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search	Date of mailing of the international search report
31 August 1999	06 -09- 1999
Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 99/00504

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 9716894 A1 (TELEFONAKTIEBOLAGET LM ERICSSON), 9 May 1997 (09.05.97), page 1, line 24 - page 2, line 19; page 4, line 2 - page 5, line 18; page 6, line 23 - line 25	1-5,7-11

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INTERNATIONAL SEARCH REPORT
Information on patent family members

02/08/99

International application No.
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